An elevated gain DC-DC converter with active switched inductor for PV application

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ABSTRACT

Innovative power electronic converters have emerged because of renewable energy expansion in the past two decades. Direct current DC grids can operate independently or connected to power grids. A DC grid has distributed generation (DG) units, such as solar panels and, fuel cells. It is necessary to have a DC-DC converter in DC grids to raise output voltage. Boost converters have limited voltage gain, and their switching stress is often equal to their output voltage. This work proposes a converter which gives high gain and less stress when compared to other recent converters. At 0.8 duty ratio, this converter produces an elevated gain of 59. An experimental prototype is built for the proposed converter and the results are presented.

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1. INTRODUCTION

The low output voltage from direct current DG source, necessitates the use of high gain boost converters to increase gain. Recently a wide variety high gain DC-DC converter have been published in literature which are mainly employed to increase the low voltage obtained from solar photovoltaic (PV) and fuel cell [1]–[11]. A “Two Tier converter” with voltage stress reduction is mentioned in [12]. The converter provides elevated gain of voltage at a low duty ratio. In addition, single control circuit is required as two switches operate concurrently. Converter in [13] is controlled by a switch with a low voltage stress in it. In the case of a continuous input current, a filter is not needed at the converter's input which makes this converter suitable for fuel cells. A converter that steps up low value of DC voltage to high value that uses quasi-Z-source network is suggested in [14]. A switched inductor, a passive switched inductor, a switched capacitor cell, and a non-isolated auxiliary switch are proposed as converter substructures in [15]. Rajabi *et al*. [16] propose a high gain non-isolated boost converter.

The suggested topology features a high voltage gain and a low duty cycle ratio when compared to typical switched inductor or switched capacitor systems. A new configuration elevated gain DC-DC converter that improves the effectiveness of PV panels for powering water pumping structure is explained in [17]. A modified DC-DC converter that has a boost module and a Z-source module with a relatively high gain is proposed in [18]. Using four switches, a novel configuration of many input boost converters with fault tolerance is presented in [19]. There is a novel structure for non-isolated DC-DC converters with many inputs and different output voltage levels presented in [20]. A novel DC-DC converter with quadratic voltage gain is presented in this study. For this converter to achieve high gain, it requires only minimum switching components. In comparison to other modern topologies, this converter has a lower voltage stress [21]. We

propose a novel high gain converter in this study. In compared to the other converter, the advantages of this converter include better efficiency and lower voltage across the switching components. A verification of proposed converter's theory is achieved through experimental study.

2. PROPOSED CONVERTER ANALYSIS

The suggested converter that provides elevated gain is presented in Figure 1. It comprises of dual switches S_{w1}, S_{w2}, two inductors L_1, L_2, 4 diodes D_1 to D_4 and 4 capacitors C_1 to C_4 and a load resistance. Here both the switches are made to operate at the same interval. The analysis is carried out assuming that the switches are ideal. Also, the capacitor voltage is assumed constant. The different switching waveforms of the suggested converter for continuous conduction mode (CCM) is depicted in Figure 2.

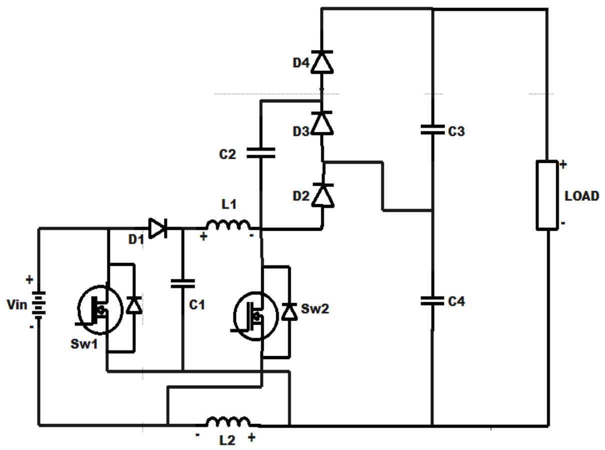

Figure 1. Configuration of suggested converter

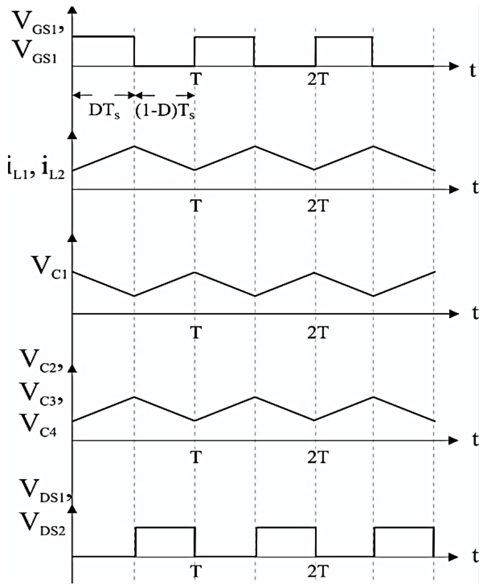

Figure 2. Key switching waveforms

Mode 1 (S_{w1} and S_{w2} ON): Figure 3 reveals the mode 1 operation of the converter. In this mode, switches S_{w1} and S_{w2} are in ON state. The diode D_3 conducts whereas diodes D_1, D_2 and D_4 are OFF. The inductor L_1 is getting charged by the supply V_{in} and inductor L_2 gets magnetized by capacitor voltage V_{c1} and supply Vin. During this mode, capacitors C_3 and C_4 discharges into the load. The mode 1 operation is governed by the following set of voltage given in (1) to (3).

$$V_{L1} = V_{in} + V_{c1} \tag{1}$$

$$V_{L2} = V_{in} \tag{2}$$

$$V_0 = V_{c3} + V_{c4} \tag{3}$$

Mode 2 (S_{w1} and S_{w2} OFF): The converter operation in mode 2 is represented in Figure 4. Both switches are in OFF state during this mode. Diodes D_1, D_2 and D_4 conducts while diode D_3 is OFF. The inductors L_1 and L_2 discharges during this mode. The voltage pertaining to this mode are presented in (4) to (6).

$$V_{L2} = V_{in} - V_{c1} \tag{4}$$

$$V_{L1} = V_{C1} - V_{c4} \tag{5}$$

$$V_o = V_{C3} - V_{c4} \tag{6}$$

Volt-sec balance across L_1 yields the following set of as (7) and (8).

$$(V_{in} + V_{c1}) \times DT + (V_{c1} - V_{c4})(1 - D)T = 0 \tag{7}$$

$$V_{c4} = \frac{V_{in}(1+D-D^2)}{(1-D)^2} \tag{8}$$

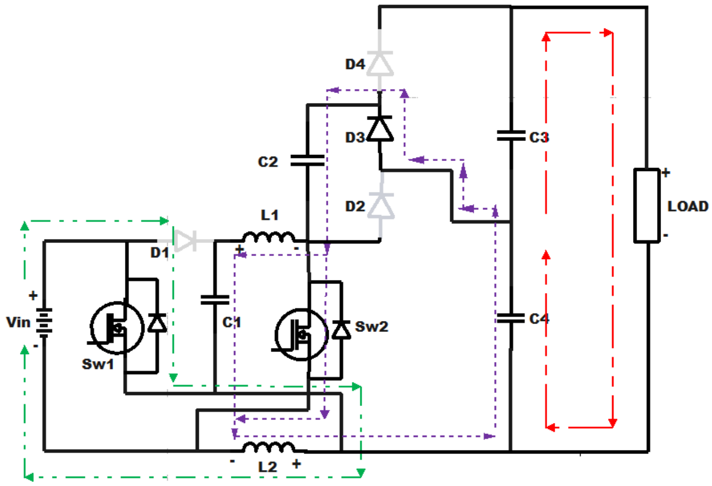

Figure 3. Mode 1 operation

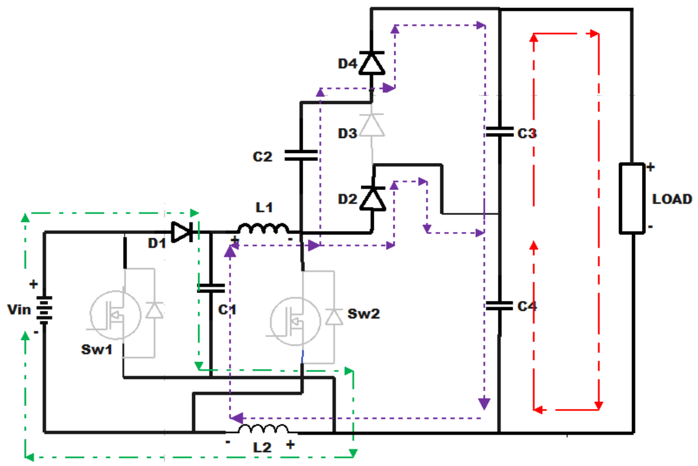

Figure 4. Mode 2 operation

Volt-sec balance across L_2 yields the following set of as (9) and (10).

$$V_{in} \times DT + (V_{in} - V_{c1})(1-D)T = 0 \tag{9}$$

$$V_{c1} = \frac{V_{in}}{(1-D)} \tag{10}$$

$$V_{c2} = V_{c3} = \frac{V_{in}(2-D)}{(1-D)^2} \tag{11}$$

The converter's voltage gain is mentioned in (12).

$$M = \frac{V_o}{V_i} = \frac{(3-D^2)}{(1-D)^2} \tag{12}$$

Switches S_{w1} and S_{w2} are subjected to voltage stress as described in (13) and (14).

$$V_{Sw1} = \frac{V_{in}}{(1-D)} \tag{13}$$

$$V_{Sw2} = \frac{V_{in}}{(1-D)^2} \tag{14}$$

3. COMPARATIVE STUDY

We compare the suggested converter with other recent converters [21]–[25] with respect to number of switching components, switching stress and voltage gain and is presented in Table 1. Ahmad *et al*. [21], total components utilized are 8 and is less than the suggested converter. Nevertheless, the voltage gain is comparatively less compared to proposed converter. By comparing the proposed converter with the converter in [22], the proposed converter produces a gain of more than 83.89 %. The converters presented in [23], [24] and [25] use high number of components compared to suggested converter.

Table 1. Assessment of proposed converter with other converters

Topology	Total inductors	Total capacitors	Total switches	Total diodes	Overall components	Voltage stress (V_S/V_{in})	Voltage gain
[21]	2	2	2	2	8	$\frac{V_{sw1}}{V_{in}} = \frac{1}{(1-D)}; \frac{V_{sw2}}{V_{in}} = \frac{1}{(1-D)^2}$	$\frac{1+D-D^2}{(1-D)^2}$
[22]	2	3	1	4	10	$\frac{V_{sw}}{V_{in}} = \frac{1}{(1-D)}$	$\frac{3+D}{2(1-D)}$
[23]	4	3	2	7	16	$\frac{V_{sw1}}{V_{in}} = \frac{2}{(1-D)}; \frac{V_{sw2}}{V_{in}} = \frac{(1+D)}{(1-D)}$	$\frac{3+D}{(1-D)}$
[24]	4	6	1	3	14	$\frac{V_{sw}}{V_{in}} = \frac{1}{(1-D)}$	$\frac{3D}{(1-D)}$
[25]	2	5	2	5	14	$\frac{V_{sw1}}{V_{in}} = \frac{1}{(1-D)} \frac{V_{sw2}}{V_{in}} = \frac{1}{(1-D)}$	$\frac{4}{(1-D)}$
Proposed	2	4	2	4	12	$\frac{V_{sw1}}{V_{in}} = \frac{1}{(1-D)}; \frac{V_{sw2}}{V_{in}} = \frac{1}{(1-D)^2}$	$\frac{3-D^2}{(1-D)^2}$

4. EXPERIMENTAL RESULTS

The suggested converter prototype model is developed in laboratory and the experimental results are verified. Table 2 shows the parameter values and devices used in the prototype model and Figure 5 shows the experimental prototype. The prototype model is examined for a power rating of 100 W and a duty cycle of 0.48. An output voltage of 100 V is obtained for an input voltage of 10 V with a gain of 10 and is revealed in Figure 6. The current through inductors L_1 and L_2 are shown in Figures 7 and 8 respectively.

Table 2. Prototype specification

Element	Rating\Model
Vin	10 V
Po(max)	100 W
Frequency	20 kiloHertz
Inductor	L_1=750 µH L_2=330 µH
Capacitor	C_1=C_2=33µF, C_3=220 µF C_4=100 µF
S_{w1} and S_{w2}	IRFP240
D_1 to D_4	MBR6045PT

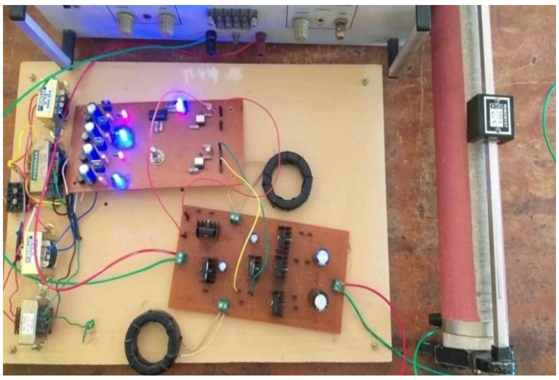

Figure 5. Experimental prototype

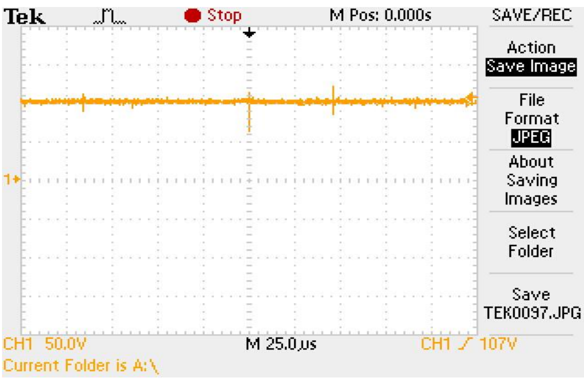

Figure 6. Output voltage

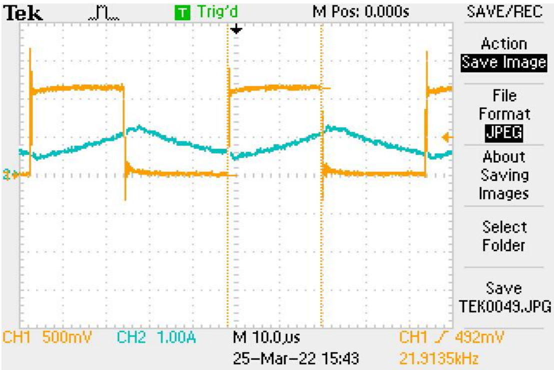

Figure 7. Current in inductor L_1

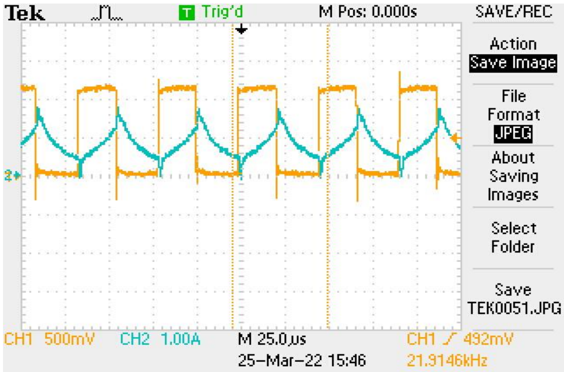

Figure 8. Current in inductor L_2

5. CONCLUSION

A novel high gain converter is proposed, and its performance is verified by testing a developed prototype model in laboratory. To boost gain of voltage, a voltage multiplier circuit is introduced in the proposed system. The suggested converter improves the voltage gain of the converter by 10%. In the suggested converter, voltage stress is less and converter's maximum efficiency was determined to be 74% for V_{in} of 10 V. The output of the suggested converter is about 100 V and is suitable for solar PV applications.

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